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A Minimum Cost Handover Algorithm for Mobile Satellite Networks

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Abstract

For mobile satellite networks, an appropriate handover scheme should be devised to shorten handover delay with optimized application of network resources. By introducing the handover cost model of service, this article proposes a rerouting triggering scheme for path optimization after handover and a new minimum cost handover algorithm for mobile satellite networks. This algorithm ensures the quality of service (QoS) parameters, such as delay, during the handover and minimizes the handover costs. Simulation indicates that this algorithm is superior to other current algorithms in guaranteeing the QoS and decreasing handover costs.

Keywords: mobile satellite networks; satellite handover; rerouting; QoS

1 Introduction

The low earth orbit (LEO) satellite systems will be an integral part of the next generation telecommunications infrastructures because they provide global coverage to support the areas with and without terrestrial wireless networks. As LEO satellites are of low altitude type, their systems can provide small end-to-end delays with low power requirements from both the satellites and terminals. However, because the footprints of LEO satellites move as the satellites traverse their orbits, the user should handover frequently between them. The inherent mobility of the LEO satellites might cause troubles to keep the user connections. Thus, in order to avoid disruption of ongoing calls resulting from satellite movements, the problem of satellite handover must be solved[1].

Because of ceaseless alternation of coverage regions of individual satellites, the sources or the destination terminals on the ground might not stay in the coverage region of the initial source or destination satellites throughout the communication. When the coverage region of a terminal changes from the satellite A to the satellite B, the LEO satellite systems need to transfer this terminal from the satellite A to the satellite B. This is termed as satellite handover. The satellite handover will result in participation of new satellites into the existing connection route, which is different from the mobile terminal handing over in terrestrial cellular systems. During the handover, the existing connection route should be updated accordingly[2-3].

The approaches to solve satellite handover problems have attracted attention of many researchers recently[4-7]. Several works pointed out that the optimal path of ongoing service would be broken down after satellite handover and the quality of service (QoS) requirements of ongoing service would

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be destroyed because of the excessive route re-establishment delay or choices of nonoptimal path for the connection[5]. There are two main solutions to the new routes after handover these days. The first one is the complete rerouting that determines a whole new route after a handover. Although this solution is the optimal one for the particular connection, it causes signaling overhead and excessive route establishment delay, which might result in handover call blocking. The other is the partial rerouting. Simple in implementing and causing much less overhead in the network compared, with the complete rerouting notwithstanding, this settlement affords the route that is not optimal and might cause inefficient utilization of the satellite resources[6]. The footprint handover reroute protocol(FHRP)[7] paid an equal attention to both complete rerouting and partial rerouting. When a connection needs handover, it will find out a new path quickly by augmenting the existing route to guarantee less handover delay, and, after certain time intervals, will update this augmented route to an optimal one for this connection. However, in practice, it is difficult for the FHRP to select the update interval, which might cause excessive nonoptimal paths. In contrast, the FHRP also ignores the requirements of ensuring the QoS being handed over. Another study[8] admitted that the frequency of rerouting can influence the network performance, but it did not indicate the optimal rerouting condition.

This article proposes a satellite handover rerouting algorithm, termed the satellite networks minimum cost handover (SMCH) algorithm, which is capable of guaranteeing the QoS of the handover and minimizing the operational costs. Like the FHRP, the SMCH consists of two phases: route augmentation and rerouting. Furthermore, the algorithm attaches importance to whether the rerouting is needed after handover. As a determinant of the rerouting, the handover cost comprises two parts: the excessive cost of nonoptimal path after route augmentation and the signaling cost after rerouting. Stresses are laid on minimizing the excessive cost after satellite handover.

2 Model of Rerouting Triggering Scheme

The satellite network is obliged to pay the excessive costs to maintain the ongoing service when the satellite handover occurs. It is called handover cost. Fig.1 shows the assumption about the handover cost. The route for users A and B will go round in the following order: $S_2 \rightarrow S_1 \rightarrow S_4 \rightarrow S_7 \rightarrow S_8 \rightarrow S_9$ if the route augmentation is used to guarantee less handover delay after handover. Nevertheless, the optimal path for users A and B is $S_2 \rightarrow S_3 \rightarrow S_9$, of which the cost is less than the path $S_2 \rightarrow S_1 \rightarrow S_4 \rightarrow S_7 \rightarrow S_8 \rightarrow S_9$. To reduce this excessive cost paid by the satellite network after the route augmentation, the rerouting must be used in the satellite node S_9. After the rerouting, the optimal path of $S_2 \rightarrow S_3 \rightarrow S_9$ can be obtained but the signaling cost for the route should also be paid. Thus, in minimizing the handover cost, the selection of rerouting interval is the decisive factor because the frequent rerouting attempts waste the satellite network resources, for a large rerouting interval results in the prolonged use of a nonoptimal route.

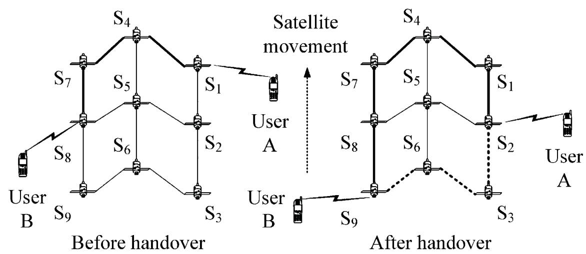

Fig.1 Satellite handover.

Next, it should be determined whether rerouting is needed after a route augmentation when a handover occurs between the users A and B. Let C represent the cost of a service to users A and B when the route is of an optimal path, C_{augment} be the cost of a service to users A and B after route augmentation, and C_{signal} be the signaling cost of rerouting. Then, after rerouting, the cost of a service to the users A and B is $C_{\text{reroute}} = C_{\text{signal}}+C$. Given $\gamma = C_{\text{signal}}/C$, then $C_{\text{reroute}} = (1+\gamma)C$. The γ depends on which the service is provided to. For example, for the video service that needs a large bandwidth, C is very big, and γ is rather small. In contrast, for the voice service, γ is quite big.

The route augmentation can be performed very fast because the existing route only needs local changes. However, the resultant route is not guaranteed to be optimal. So this article uses route augmentation first after handover, and then, decides whether or not to update the route by rerouting. This is called rerouting triggering scheme.

There are two reasons to decide whether the rerouting is needed after the route augmentation. First, as stated above, because the new route stemmed from the route augmentation might not be optimal, it possibly could not guarantee the requisite QoS. So the rerouting must be performed if the new route is not able to maintain the requisite QoS. Second, the handover cost is another factor of rerouting triggering that should be considered given a satisfactory route out of the route augmentation. The selection of rerouting triggering scheme is dependent on the costs C_{augment} and C_{reroute}. If $C_{\text{augment}} > C_{\text{reroute}}$, the handover cost will diminish after rerouting, which makes it necessary to trigger the rerouting. If $C_{\text{augment}} < C_{\text{reroute}}$, the rerouting should be obviated because the signaling cost of rerouting will result in an increased handover cost.

To sum up, the two conditions that determine whether or not to use the rerouting triggering scheme after the route augmentation are: the inability of the new route to warrant the quality of service and $C_{\text{augment}} < (1+\gamma)C$.

3 SMCH Algorithm

The handover involves two satellites, so the connection route should be modified to include the new satellite node in it. This change can be achieved with the SMCH algorithm, which consists of the route augmentation and rerouting phases. In the route augmentation phase, the SMCH algorithm finds out a direct link between the new satellite node and the existing route. Simple to compute and implement, this phase can be performed in the satellite node possessive of restricted computing capability thereby achieve the less handover delay. The rerouting phase consists of rerouting triggering estimation and rerouting implementation. Following route augmentation, the SMCH algorithm will first estimate whether the rerouting is needed or not. And if it is needed, the SMCH algorithm should optimize the route. This phase is complex and is difficult to implement in satellite node, it can be implemented in a ground gateway.

The process of the SMCH algorithm can be roughly described as follows.

Given a mobile terminal A in the coverage region of the satellite S and the other B in that of the satellite T, the optimal routing for the terminals A and B is U with the cost of C. The current routing from the terminal A to B is U_1, and U_1 = A$\rightarrow$S$_i\rightarrow$S$_j\rightarrow$S$_m\rightarrow\cdots\rightarrow$S$_k\rightarrow$B. A set W is defined to represent all the satellite nodes of U_1, and W = {S$_i$, S$_j$, S$_m$,$\cdots$,S$_k$}. At time t, the coverage region of the satellite S left by the terminal A is covered by a new satellite S_1. Then the satellite S decides to start the SMCH algorithm and the rest of handover is handled as follows.

(1) Initialization of handover

The satellite S sends a service handover request message including the current routing U_1 to the satellite S_1. If the gateway station of the satellite S is different from that of the satellite S_1, it will send another message including the QoS to this service, and the cost C etc. to the gateway station of the satellite S_1.

(2) Route augmentation

When the satellite S_1 receives a message from the satellite S, the route augmentation will be run to obtain a new path from the satellite S_1 to the terminal B quickly. If this phase ends up in success, the instantly established service connection would send a successful message to the gateway station to initiate the rerouting phase. Otherwise, an unsuccessful message would also be done.

By modifying the current routing U_1, the route augmentation allows a path from satellite S_1 to the terminal B, which can be obtained quickly. The process of route augmentation can be detailed as follows:

① Begin;

② S_1 receives a service handover request message;
③ S_1 checks whether the node $S_1 \in W$;
④ If $S_1 \in W$, then:

A) The portion of W up to S_1 is deleted. For example, if $S_1 = S_m$, the S_i and S_j are removed. Then the W turns to be $\{S_1,\cdots,S_k\}$ and the new route $A\rightarrow S_1\rightarrow\cdots\rightarrow S_k\rightarrow B$;

B) Based on the new route, modify the U_1 and W. Send the new U_1 and W to the gateway station;

C) S_1 produces successful message about route augmentation and sends it to the gateway station.

⑤ Or else:

A) Search a direct link with a sufficient capacity to support the service from S_1 to one of the satellite node in W starting with the last member of W. For example, S_1 checks whether a valid direct link between S_1 and these nodes in W can be found from S_k to S_i;

B) If this link is found, then:

a) The link will be augmented to the original route and the unused portion of the previous route is removed. For example, suppose that a valid link between S_1 and S_m is found, then the new route becomes $A\rightarrow S_1\rightarrow S_m\rightarrow\cdots\rightarrow S_k\rightarrow B$, and the $W=\{S_1, S_m,\cdots, S_k\}$;

b) Based on the new route, modify the U_1 and W. And then send new U_1 and W to the gateway station;

c) S_1 produces a successful message about route augmentation and sends it to the gateway station;

C) Or else:

S_1 produces an unsuccessful message about route augmentation and sends it to the gateway station.

⑥ End.

(3) Rerouting

When the gateway station receives a successful or an unsuccessful message about route augmentation from the satellite S_1, the station first checks whether or not the rerouting is necessary. If it is, the original routing algorithm is performed. In this case, the key problem is whether to trigger the rerouting or not. Fig.2 lists the rerouting process.

In this phase, if the rerouting triggering scheme of the handover service is satisfied, the station will produce a new optimal path from A to B to replace the U_1 obtained in route augmentation. Otherwise, the SMCH algorithm will be over.

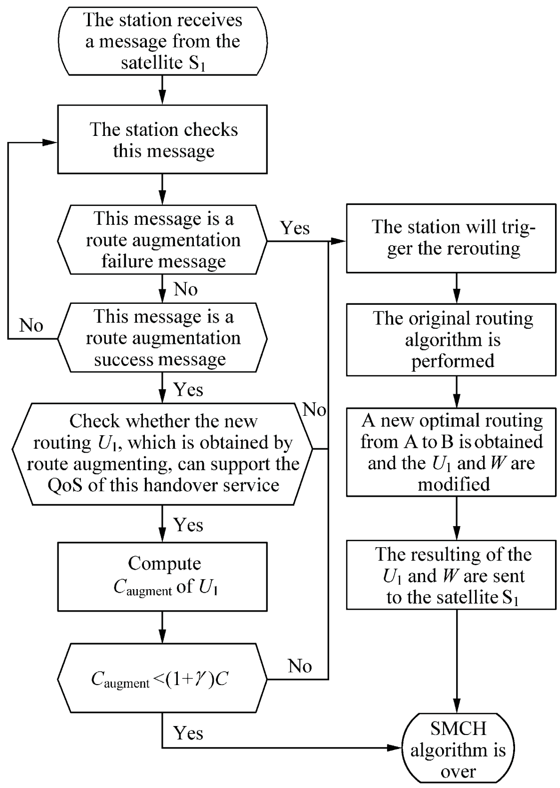

Fig.2 Detailed process of rerouting.

4 Simulation and Discussion

Similar to FHRP, the lower computational and space complexities of the resultant phase from the SMCH algorithm route augmentation is quite suitable for the use in the satellite nodes, which are limited by computing capability. Although the complexity of rerouting phase might be increased because of the involvement of the original QoS routing algorithm, it might be alleviated by the station gateway, which has more computing resource.

This section will evaluate the performance of the proposed SMCH algorithm and compare it to the FHRP algorithm. The experimental setup comprises: ① the satellite network G chooses the Teledesic constellation[9] with 12 circular polar orbits, each containing 288 satellites; the orbit, 1 375 km high, has 8 neighbors with cross-seam inter satellite links

(ISLs) for every satellite. ② the service η is a Poisson traffic, and the mean duration μ = 5 min. ③ mobile users are considered uniformly distributed in the coverage region of every satellite. ④ the simulation will generate 1 000 calls at random, and the simulation generates a new call every time the old one is over. The result is the average of the 1 000 data. The simulation includes three groups as follows.

4.1 Handover cost of algorithm

This article will compare the handover cost of the SMCH algorithm with that of the FHRP algorithm. Let SC_r represent the ratio of the handover costs between the two algorithms, i.e., SC_r = (the handover cost of SMCH algorithm)/(the handover cost of FHRP algorithm).

As seen from Fig.3, the SMCH has a lower handover cost than the FHRP, for it can save 15% network resources after handover. This algorithm is especially suitable for application in satellite networks, which needs a very costly resource.

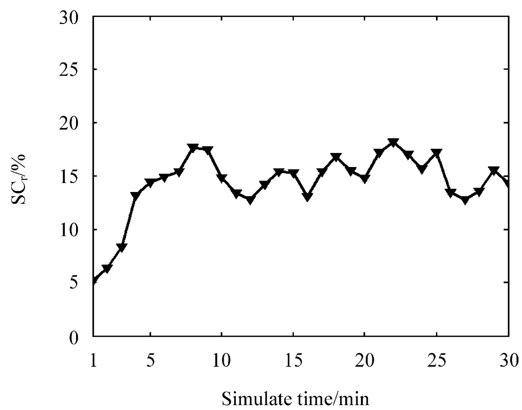

Fig.3 SC_r results.

4.2 Performance of QoS guarantee

This article compares the QoS guarantee performance of SMCH with that of the FHRP algorithm in terms of delay constraints, which is something very important for satellite networks.

Figs.4-5 show a better delay performance which the SMCH possesses than that the FHRP does. As shown in Fig.4, under the same delay constraint, the average delay of the SMCH is less than the FHRP, and in Fig.5, the FHRP results show lots of paths that fail to satisfy the delay constraints, which might violate QoS requirement of ongoing calls. For example, when the delay constraint equals to 80, nearly 50% of paths delay will exceed the delay constraint for the FHRP. In contrast, nearly 10% of calls will be rejected by the SMCH because the paths that satisfy the delay constraint for these calls can not be found after handover.

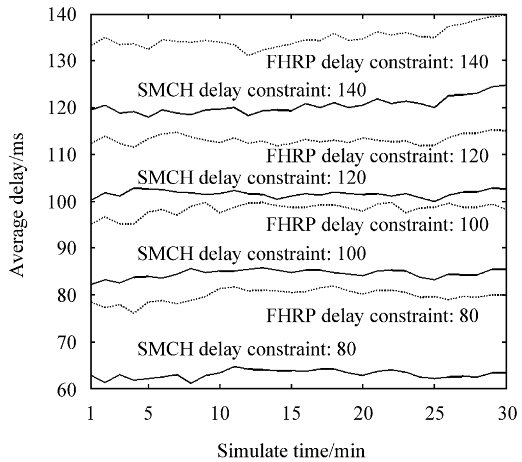

Fig.4 Averages of different delay constraints.

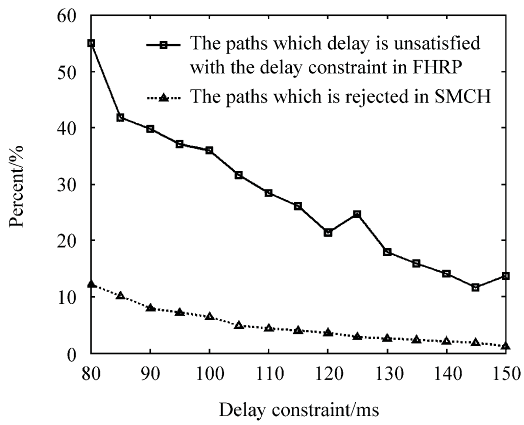

Fig.5 Percent of path failing to satisfy the delay constraint.

4.3 Influence of γ

As shown in Fig.6, the rerouting probability after handover increases with the decrease of γ. As γ declines below 0.2, it drops rapidly after exceeding 20%. This suggests that, the best performance for different services can be attained by changing the value of γ to enable the SMCH to adjust the rerouting probability. This makes the SMCH superior to the FHRP, of which the rerouting probability is constant for every kind of service. For example, because the signaling cost of some services, such as of data or of video, is so small that a small value of γ could be given to improve the rerouting probability after handover and cut the excessive cost of nonoptimal path in the network. In contrast, for other services, such as of voice, a big value of γ should be given to decrease the rerouting probability after handover and after signaling the cost in the network.

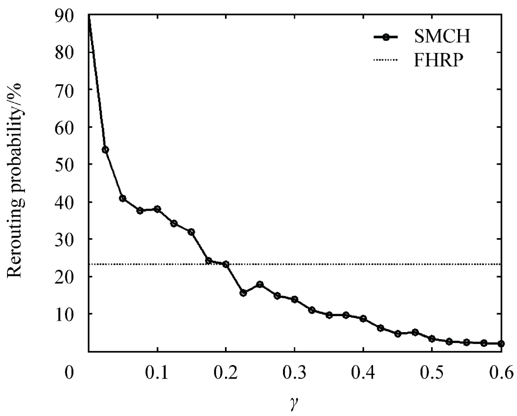

Fig.6 Relationship between γ and rerouting probability.

5 Conclusions

Satellite handover can not only worsen the QoS performance of ongoing services but also cause excessive wastage of resource affecting the performance of whole satellite network. Focusing attention towards the satellite handover problem, this article proposes a novel SMCH algorithm, which retains the user connections of ongoing service by using the simple route augmentation and minimize excessive wastage of resource by triggering rerouting properly. The related simulation shows that, having an advantage over other existing algorithms, such as FHRP, this novel algorithm can guarantee the QoS performance of ongoing services while maintaining full utilization of network resources after handover.

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